SODIUM CYANIDE AS A FISH POISON

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ABSTRACT

Laboratory and field experiments were conducted to evaluate the use of sodium cyanide as a fish poison. At concentrations of 1 p.p.m. sodium cyanide and at a variety of temperature and pH conditions, effective kills of a number of different species of warm-water fishes were produced. The cost of the sodium cyanide was approximately 68 cents an acre foot. Application required little time and equipment. In small farm ponds the water was toxic for about 4 days.

The most significant findings of the study relate to the removal of live fishes during poisoning operations. After application of 1 p.p.m. sodium cyanide to small farm ponds, fishes began to surface within 5 to 30 minutes. Affected fishes removed and placed in fresh water completely revived within 5 to 30 minutes. The length of the removal period for centrachids was approximately 1 hour. The survival of the salvaged fishes was excellent. Many possible uses of sodium cyanide in fishery management are suggested.

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This paper is part of a thesis submitted to the Department of Zoology in the Graduate School of Southern Illinois University in partial fulfillment of the requirements for the degree of Master of Science. It is published here because of its general interest in the field of fishery management.

!!! C A U T I O N !!!

Cyanides are deadly poisons. Death can result from swallowing small amounts of the salts or the acid and from breathing low concentrations of the gas, hydrogen cyanide. When sodium cyanide is added to water, hydrocyanic acid is produced and a small amount is evolved at the surface as hydrogen cyanide. It is conceivable that under certain conditions enough gas could accumulate to be dangerous. The greatest dangers are accidental ingestion of the salt and inhalation of the gas released by the action of an acid that has been allowed to come in contact with sodium cyanide. Sodium cyanide should be used only by technicians acquainted with it.

At the low concentrations of sodium cyanide used for fish removal, there is little danger to domestic animals as a result of drinking the treated water. Mammals would have to drink from two to three times their body weight to receive a lethal dose. The writer observed no noticeable effect on a herd of ponies that obtained their principal supply of water from a pond that had been treated with 1 p.p.m. sodium cyanide.

INTRODUCTION

Within the past 20 years the use of fish poisons has gradually become accepted as an important tool in freshwater fishery management. However, no entirely satisfactory poison is in use today. There is definite need for a fish poison that will facilitate the removal and permit the revival of affected fishes. Of the fish poisons presently in use, rotenone is the only one that enjoys widespread acceptance and popularity. Rotenone does not allow the revival of affected fishes but does possess the desirable properties of being highly toxic to fishes and dissipating within a reasonable length of time. The purpose of this study was to evaluate the use of sodium cyanide as a fish poison, using as criteria all three of the above properties.

Considerable literature exists dealing with the toxicity of cyanides to fishes (Burdick and Lipschuetz, 1948; Doudoroff, 1956; Downing, 1954; Ellis, 1937; Lipschuetz and Cooper, 1955; Renn, 1955). In general, these works view cyanides in relation to industrial pollution. No reference was found to sodium cyanide or other cyanide compounds for use in fishery management.

MATERIALS AND METHODS FOR LABORATORY EXPERIMENTS

Three series of laboratory experiments were designed to determine toxicity, duration of toxicity, and whether affected fishes could revive. The information obtained from these experiments was utilized later in field investigations.

Six species of fishes were used in the laboratory experiments: longnose gar (Lepisosteus osseus), goldfish (Carassius auratus), carp (Cyprinus carpio), yellow bullhead (Ictalurus natalis), largemouth bass (Micropterus salmoides), and green sunfish (Lepomis cyanellus). The fishes were collected from various ponds near Carbondale, Illinois. They were kept in the laboratory in large galvanized holding tanks supplied with Carbondale municipal water. The water in the tanks was aerated with compressed air. Periodically, part of the water was drained and fresh water allowed to drip into the tanks. The tanks were located in a partially shaded and well ventilated glass room where the temperature closely followed that of the outdoors. Green sunfish, yellow bullhead, carp, and goldfish were fed canned horsemeat. The bass and longnose gar were fed small minnows. All the fishes seemed to be in good health during the course of the experiments. Before being submitted to any of the tests the fishes were kept in the holding tanks from 10 to 30 days. Food was withheld for at least 2 days preceding the tests. Total lengths of the fishes were recorded to the nearest inch. Ranges in length were as follows: longnose gar, 11 to 13 inches; goldfish, 2 to 4 inches; carp, 8 to 12; yellow bullhead, 4 to 6; largemouth bass, 7 to 12; and green sunfish, 2 to 4.

The water used as a diluent -- the water to which the poison was added to form the test solution -- in all of the experiments was taken from the same holding tanks that were used to keep the experimental fishes. At the beginning of each experiment determinations were made of the pH and temperature of the diluent. Generally, subsequent determinations were not made. The pH values were determined colorimetrically. The original conditions of the diluent were modified for 4 toxicity experiments. Acetic acid was used to lower pH values to 5.5 in two of them. In the other two, temperatures were lowered to 54°F. by the addition of ice.

Two sizes of glass aquariums were used. In tests made in the large aquariums 100 liters of the test solution was used. Two different volumes of solution were used in the smaller aquariums, 25 liters and 50 liters. Fifty liters of solution was used in 80 percent of the experiments conducted.

The sodium cyanide used in all experiments was in the original form, a small pellet weighing approximately one ounce, sold under the trade name, Cyanegg. Cyanegg contains a

minimum of 96 percent sodium cyanide. On each day that tests were run a fresh solution of sodium cyanide was prepared. A pellet was crushed and 1 gram of it was weighed and dissolved in 200 milliliters of distilled water. The addition of measured quantities of this solution to the test aquariums containing the diluent provided the desired concentrations which were recorded in p.p.m. sodium cyanide.

Although the test solutions were not aerated artificially for any of the laboratory experiments and no determinations were made, the dissolved oxygen concentrations were apparently sufficient. Proper controls were run for each of the tests, and no loss of fishes occurred in control aquariums during the course of the experiments.

Fish were removed from the holding tanks and placed in an aquarium containing the diluent 10 to 15 minutes before the addition of the desired concentration of poison. If 100-percent mortality did not occur within 72 hours the tests were terminated. Continuous observations of the behavior of the fishes were made for 2 or 3 hours and if complete mortality had not occurred within this period, further observations were made at irregular intervals as necessary. When there was no response to gentle prodding, the fishes were considered to be dead and the time required to produce 100-percent mortality was recorded to the nearest one-tenth of an hour.

The green sunfish was the only species used in laboratory tests designed to indicate the duration of the toxicity period. Test solutions used were chosen from those that had produced 100-percent mortality in toxicity experiments. Beginning 24 hours after the addition of the poison groups of test fish were placed in an aquarium containing the test solution at intervals of 24 hours until all fish in each group survived for 24 hours. The surviving fish were then observed for one week. The percentage of survival at 24, 48, 72, and 168 hours was noted for each group.

Green sunfish and largemouth bass were used in laboratory experiments to determine if the fishes would revive after being removed from solutions of the poison. Four test fish were transferred from the holding tanks to an aquarium containing the diluent. The fish were allowed a period of 10 to 15 minutes to settle down. Enough poison was added to make the concentration 1 p.p.m. After being exposed for a designated period, two fish were removed and placed in an aquarium containing untreated water similar to the diluent. The time required for complete revival was noted. The fish were considered to be completely revived if they exhibited normal response to external stimuli. After their revival, the fish were observed for at least 1 week to determine their survival. The time required to produce 100-percent mortality was noted for the two fish that remained in the test solution.

MATERIALS AND METHODS FOR FIELD EXPERIMENTS

Eight farm ponds or pools near Carbondale, Illinois, were used for the field experiments. Table 1 presents some of the physical and chemical characteristics and the kinds of fish in each pond. In addition, the concentration of sodium cyanide used and its method of application for each pond is shown. The poison was applied in two ways. For the larger ponds, a burlap sack containing the pellets of sodium cyanide was suspended from a stake in the wash of a 10-horsepower outboard motor placed either on a boat or a rack and, generally, allowed to run at about half throttle for 10 minutes and then shut off. For the smaller ponds, the pellets were dropped into a small-meshed dip net and allowed to dissolve while the net was being moved through the water around the edges of the pond. All pH values were determined colorimetrically, except that in pond 7, which was determined electrometrically.

The effectiveness of the toxicity of the poison was estimated for six ponds by using the results from intensive seining operations. These estimates were further supported by observations made during and following poisoning operations.

Determination was made of the duration of toxicity in two ponds. Twenty-four hours after the poison had been applied a group of 6 green sunfish in a wire cage was placed in the pond at a depth of approximately 3 feet.

Table 1.--Experimental conditions for eight farm ponds used in evaluating sodium cyanide as a fish poison

Pond no.	Area (est. in sq. ft.)	Volume (est. in cu. ft.)	Surface temp. (°F.)	pH	Conc. of NaCN (p.p.m.)	Method of application of NaCN	Fish population
1	15,000	45,000	78	7.2	1.0	Motor	Green sunfish (Lepomis cyanellus), golden shiner (Notemigonus crysoleucas).
2	12,000	46,000	74	6.0	1.0	Motor	Largemouth bass (Micropterus salmoides), golden shiner, black bullhead (Ictalurus melas).
3	525	1,000	62	6.8	1.0	Dip net	Swamp darter (Ethoestoma gracile), green sunfish, yellow bullhead (Ictalurus natalis), black bullhead, golden shiner, gambusia (Gambusia affinis).
4	1,050	1,800	66	7.3	1.0	Dip net	Flier sunfish (Centrachus macropterus), green sunfish, yellow bullhead, black bullhead, golden shiner, gambusia.
5	3,600	4,000	42	7.6	1.0	Dip net	Steel-colored minnow (Notropis whippli), golden shiner.
6	2,000	5,000	51	7.3	1.5	Dip net	Goldfish (Carassius auratus).
7	5,000	16,000	63	9.7	1.0	Motor	Black crappie (Pomoxis nigro-maculatus), green sunfish, largemouth bass, black bullhead, carp (Cyprinus carpio).
8	28,000	112,000	67	7.5	1.0	Motor	Swamp darter, white crappie (Pomoxis annularis), warmouth (Chaenobryttus gulosus), bluegill (Lepomis macrochirus), green sunfish, largemouth bass, yellow bullhead, golden shiner, smallmouth buffalo (Ictiobus bubalus), grass pickerel, (Esox americanus), longnose gar (Lepisosteus osseus).

Thereafter, new groups of fish were placed in the cage at 24-hour intervals until all fish in one group survived for 48 hours. The percentage of survival for each group of caged fish was recorded at 24, 48, 72, 96, and 168 hours.

Operations concerned with the removal of live fishes from the poisoned ponds were

conducted on six of the eight ponds used in the field experiments. The following aspects were considered: (1) the ease with which the fishes could be removed, (2) the length of the removal period, (3) the survival of the fishes removed, and (4) the effectiveness of removal. The extent to which each of these features were considered and the methods and procedures employed varied for each of the pond experiments. This information is presented with the results reported for the removal experiments conducted in the field.

RESULTS

Toxicity

The results of the toxicity experiments are summarized in table 2. Concentrations of 1 p.p.m. sodium cyanide produced complete kills of all species of fishes tested. All green sunfish were killed at concentrations of 0.5 p.p.m., but none of the goldfish were. A few goldfish lost equilibrium after approximately 8 hours exposure, but all survived and apparently suffered no ill effects. The results for all species were not exactly comparable but they clearly indicated that goldfish, carp, and yellow bullhead were more resistant than green sunfish and largemouth bass. Low temperatures and high pH values tended to extend the time required to produce 100-percent mortality.

The acute toxicity of sodium cyanide indicated in laboratory tests was supported by the results obtained from field experiments. Intensive seining operations in six ponds conducted 10 to 30 days after application of the poison produced no live fish. Complete kills were estimated for these ponds. The estimates made for three of the ponds were further supported by the following: (1) green sunfish placed in cages in ponds 1 and 2 two days after the application of the poison suffered 100-percent mortality; (2) later applications of sodium cyanide at estimated concentrations of 2 p.p.m. in pond 1 and 3 p.p.m. in pond 3 failed to produce any fish. General observations of all of the ponds were made on days after poisoning, and live fish could not be detected in any of them. Dead fish, including the more resistant species, were found floating on all of the ponds. Ponds 7 and 8 were not seined because of their extreme brushy nature, but an effective kill was indicated by the numbers and kinds of dead fish found floating on days following the poisoning operations.

Note that the pH of pond 7 was 9.7 (table 1). Efforts in the laboratory to test the toxicity of sodium cyanide at pH values higher than this proved unsuccessful. The addition of sodium hydroxide to raise the pH to the desired levels resulted in the loss of control fish.

Duration of Toxicity

Seven laboratory experiments were conducted to indicate the duration of the toxicity period. The results of these experiments are presented in table 3. In four tests, solutions of sodium cyanide 72 hours old were found not to be toxic to green sunfish. In three tests the toxic effects lasted only 48 hours.

Results of field experiments in ponds 1 and 2 are presented in table 4. All green sunfish placed in cages in the ponds 96 hours after application of the poison survived. The period of toxicity was further indicated by restocking operations performed in pond 3. Golden shiners that had been taken as a result of another poisoning with sodium cyanide were stocked in pond 3 four days after it had been poisoned. Later observations of the pond revealed no dead fish and the results of subsequent seining operations indicated good survival.

Removal and Revival of Fishes

The results obtained from laboratory experiments conducted to determine if fishes would revive after their exposure to solutions of sodium cyanide are presented in table 5. When placed in untreated water, all fishes removed from test solutions revived within 30 minutes. None of the revived fishes was lost during the subsequent observation period of 1 week. The fishes removed from solutions in tests 4, 7, and 8 had completely lost equilibrium and were lying on the bottom of the aquarium at the time of removal.

Observations of fish behavior during revival tests and toxicity tests indicated the length of the period of removal and something of the ease with which the fishes could be removed.

Table 2.--Toxicity of sodium cyanide to six species of freshwater fishes

Species of fish	Number of tests	Number of fish per test	Temp. range of diluent (°F.)	pH range of diluent	Time required for 100% mortality	
					Minimum (hours)	Maximum (hours)
0.5 p.p.m. NaCN						
Green sunfish	2	4	76-79	7.6-8.0	4.1	6.0
Goldfish	2	4	76-82	7.1-8.0	...	...
1.0 p.p.m. NaCN						
Green sunfish	17	4	54-80	5.5-9.0	1.0	2.8
Largemouth bass	4	4	74-80	7.0-8.9	0.7	1.4
Yellow bullhead	3	5	76-80	7.0-8.2	5.1	8-10*
Carp	2	4	79-80	7.3-7.5	5-8*	8-14*
Goldfish	2	4	78-79	7.2-8.7	5-8*	44-48*
Longnose gar	2	2	73-74	7.3-7.8	3.3	4.2
1.5 p.p.m. NaCN						
Green sunfish	2	4	76-79	7.5-7.6	0.6	0.7
Goldfish	3	4	74-79	7.1-9.0	6.2	20-24*

* The exact time of 100-percent mortality was not observed

Table 3.--The duration of toxicity of solutions of sodium cyanide to the green sunfish

Test No.	Initial temp. of diluent (°F.)	Initial pH of diluent	Initial conc. of NaCN (p.p.m.)	Number of hours after addition of NaCN*	Fish				
					Number in each group	Percentage survival of each group			
						24 hr.	48 hr.	72 hr.	168 hr.
1	80	7.0	1.0	24	4	0	0	0	0
				48	4	75	50	0	0
				72	4	100	100	100	100
2	78	7.1	1.0	24	5	0	0	0	0
				48	5	0	0	0	0
				72	5	100	100	100	100
3	79	7.3	1.0	24	5	0	0	0	0
				48	5	80	60	60	60
				72	5	100	100	100	100
4	76	8.2	1.0	24	3	0	0	0	0
				48	3	100	100	100	100
5	80	8.9	1.0	24	5	0	0	0	0
				48	5	100	100	100	100
6	79	7.6	1.5	24	4	0	0	0	0
				48	4	75	75	75	75
				72	4	100	100	100	100
7	79	7.6	1.5	24	4	0	0	0	0
				48	4	100	100	100	100

*After the addition of sodium cyanide, a new group of fish was placed in the aquarium containing the test solution at intervals of 24 hours.

Table 4.--The duration of toxicity of sodium cyanide to green sunfish in two farm ponds

Number of hours after application of NaCN*	Percentage survival of each group of fish				
	24 hours	48 hours	72 hours	96 hours	168 hours
Pond 1					
24	0	0	0	0	0
48	0	0	0	0	0
72	67	67	50	50	50
96	100	100	100	100	100
120	100	100	100	100	100
Pond 2					
24	0	0	0	0	0
48	0	0	0	0	0
72	83	83	83	83	83
96	100	100	100	100	100
120	100	100	100	100	100

* After the application of sodium cyanide, a new group of fish was placed in a cage in the pond at intervals of 24 hours. Each group contained six fish

Table 5.--The revival of green sunfish and largemouth bass after exposure to test solutions of 1 p.p.m. sodium cyanide

Test No.	Diluent		Fish*		
			Removed from solution		Left in solution
	Temperature (°F.)	pH	Exposure (minutes)	Complete revival (minutes)	Time required to kill (minutes)
Green Sunfish					
1	76	7.2	5	10	60
2	76	7.2	10	10	65
3	80	7.0	30	20	65
4	78	8.4	45	20	70
Largemouth Bass					
5	80	7.0	20	15	55
6	76	7.2	20	20	55
7	74	7.3	25	30	35
8	80	8.9	40	20	80

* In each test four fish were used. Two were removed from the test solutions and placed in fresh water to revive and two were left in the solution to act as controls.

Their general reaction to the poison was similar to that exhibited to deficient concentrations of dissolved oxygen. The general pattern of behavior, particularly that of the green sunfish in solutions of 1 p.p.m. of sodium cyanide, is described below:

0 to 10 minutes.--The fish appeared normal.
3 to 30 minutes.--The fish surfaced. This action was in some cases preceded or followed by vigorous swimming. During the latter part of this period they began to lose equilibrium and sink.
20 to 50 minutes.--This was a period characterized by alternate surfacing and sinking as the fish regained their equilibrium only to lose it again.
After 50 minutes.--The fish exhibited a final loss of equilibrium and sank to the bottom of the aquarium before death occurred.

Bass tended to surface at about the same time as the green sunfish. However, the periods outlined above were somewhat shorter. All of the periods were longer in the cases of carp and goldfish. The yellow bullhead showed a definite tendency not to surface and remained on the bottom of the aquarium until equilibrium was lost for the first time. The longnose gar surfaced almost immediately and remained at the surface gasping air until equilibrium was lost. Lower concentrations of poison tended to lengthen the periods while higher concentrations shortened them. At lower temperatures the time required to produce complete mortality was extended, but the length of period where the fish surfaced differed little from those at higher temperatures. All periods tended to be longer at the higher pH values.

During the later part of the surfacing period and thereafter fishes generally could be caught easily with the hand.

In field experiments removal operations were conducted on six ponds. General information on these ponds appears in table 1. A summary of these operations and the results are presented below:

Pond 2.--Attempts were made to remove only the bass present. They were removed by two men along the edges of the pond and one in a boat using dip nets. Fishes started surfacing approximately five minutes after the application of poison was started. At this time removal operations were begun and were stopped 40 minutes later. Thirty bass were removed and placed in buckets of fresh water that had been taken from the pond prior to poisoning. Twenty-eight of these fish were transported to a clean pond 11 miles distant. Upon arrival and subsequent stocking, all fish seemed to be in excellent condition. Survival was good; later observations of the stocked pond revealed no dead fish. Bass were observed feeding from 2 to 10 weeks following the operation. Two of the bass were transported to the laboratory and observed for one week. They suffered no apparent ill effects. To indicate the effectiveness of removal, the poisoned pond was observed for one week. There were great numbers of dead golden shiners and bullheads floating on the surface, but only two dead bass were detected.

Ponds 3 and 4.--Removal operations conducted on ponds 3 and 4 were similar. Green sunfish and golden shiners were removed from pond 3 and green sunfish, golden shiners, and black and yellow bullheads were removed from pond 4. In both ponds, removal operations by two men in waders using dip nets were begun when the fishes started surfacing 15 minutes after application of poison was started. Removal operations were conducted for 45 minutes in pond 3 and 75 minutes in pond 4. Twenty-five shiners and 31 green sunfish were removed from pond 3. The numbers of fishes taken from pond 4 were: bullheads, 201; golden shiners, 125; and green sunfish, 29. The green sunfish and bullheads were transported to the laboratory 20 miles away and observed for two weeks. In this period approximately 25 percent of the green sunfish and 10 percent of the bullheads were lost. (Loss of other fishes in the laboratory occurred at the same time owing to a sudden increase of chlorine in the water.) The golden shiners were transferred to other ponds within 100 yards of the poisoned pond. Later observations and seining operations indicated that survival was good. On the basis of the number of dead fishes later counted on the poisoned ponds approximately 95 percent of the sunfish and shiners and 70 percent of the bullheads were removed.

Pond 6.--In pond 6 removal of the fish was accomplished in the same manner as in ponds 3 and 4. Operations were started when the goldfish began to surface 15 minutes after application of the poison was started and were continued for 105 minutes. In this period, 1,052 goldfish were recovered and transferred to an adjacent pond. Follow-up observations revealed a total of 275 dead fish floating in the poisoned pond and no dead fish in the stocked pond.

Pond 5.--The method of removal was modified in pond 5. Two men using a 25-foot seine started removal operations 30 minutes after the start of the application of the poison and 15 minutes after the fishes started to surface. Operations were halted 30 minutes later. In this period 10 seine hauls produced approximately 15,000 golden shiners and steel-colored minnows. Most of the fishes were transferred to an adjacent pond. Later seining operations and observations indicated excellent survival. Approximately 300 of the fishes were transported back to the laboratory and observed for one week. In this period only four fishes were lost.

Pond 7.--Removal operations were performed by four men in pond 7, two with dip nets and waders along the shore and two with dip nets from a boat. The objective was to recover all bass possible and enough green sunfish and black crappie for observations of survival. Removal of the fishes began when fishes started to surface approximately 30 minutes after the application of the poison. Removal operations were halted 60 minutes later. In this period 15 bass, 400 sunfish, and 250 crappie were removed. Many more sunfish and crappie could have been taken during the 60-minute period if desired. Of the fishes removed 13 bass and 150 crappie were stocked in a pond within a few hundred yards of the poisoned pond. The remaining fishes were transported to the laboratory 15 miles distant and observed for 10 days. In this period, three crappie died. This was the only loss of fishes noted. Subsequent observations of the poisoned pond revealed no dead bass floating, although there were a great many fish of other species.

From observations made of ponds poisoned, it was possible to group the fishes according to the approximate time that they generally appeared at the surface:

5 - 15 minutes.--Swamp darter, white crappie, black crappie, flier sunfish, warmouth, green sunfish, bluegill, largemouth bass, steel-colored minnow, grass pickerel, and longnose gar.

15 - 30 minutes.--Golden shiner.

20 - 40 minutes.--Yellow and black bullheads.

30 - 60 minutes.--Carp and smallmouth buffalo.

The beginning of the removal period was marked by the appearance of fishes at the surface and termination of it was determined by the absence of fishes at the surface. Generally the maximum length of the period in which centrachids could be removed was one hour. The length of the removal period of more resistant species was somewhat longer. In pond 7, where the pH was 9.7, none of the fishes surfaced until 30 minutes had elapsed from the time of the application of poison. The removal period of all fishes was extended in this pond. The removal period for goldfish in pond 6, where the estimated concentration of poison was 1.5 p.p.m., lasted for over seven hours. In most instances where removal operations were conducted, it would have been possible to have taken more fish if the operations had been extended, but at a decidedly decreased rate. The time generally spent for removal operations approximated the length of the removal period for centrachids.

After the fishes surfaced, they were readily caught with a dip net. However during the first part of the removal period the fishes exhibited an escape response to movement and noise. They progressively became more susceptible to capture and toward the end of the removal period they could be caught with the hands.

Other results and observations

The following qualitative observations were made:

(1) Volume of test sollution.--In the laboratory no correlation was observed between volume of solution used and the toxic effects of the poison.

(2) Size of fishes.--The size of fishes as related to toxic effects was of little, if any significance. In both laboratory and field experiments, larger fishes surfaced as readily and were killed as soon as smaller ones with few exceptions.

(3) Other aquatic organisms.--General observations made during and subsequent to poisoning operations conducted in the field indicate that sodium cyanide, at the concentrations used, had little toxic effect on many macroscopic aquatic organisms or on the phytoplankton. No noticeable effect on frogs, snakes, turtles, or aquatic insects was observed. The poison caused tadpoles to surface, but they were not killed. Phytoplankton growth appeared as dense or denser after poisoning operations.

DISCUSSION

The results obtained from laboratory and field experiments indicate that sodium cyanide meets the three criteria that were employed in this study for its evaluation as a fish poison.

The effective toxicity of sodium cyanide at low concentrations was demonstrated. Complete kills of a number of different species of warmwater fishes were produced at a variety of temperature and pH conditions. The toxic effect seemed to be less in waters exhibiting high pH values or low temperatures. Others have suggested that the toxicity of cyanide solutions to fish is largely the result of hydrocyanic acid molecules rather than the cyanide ion (Doudoroff, 1956). If this is true, the apparent decrease in toxic effects at higher pH values can be explained in part by the HCN-CN ratio that exists at different levels of pH. Wilne (1950) states "the proportion of free hydrocyanic acid available increases rapidly as the pH decreases from a value of about 10." However, even though the toxic effect appeared to be less, results in this study indicated that the kill could be effective at a pH of 9.7. Evidently there is enough hydrocyanic acid present, even at these high pH values, to kill fish effectively. Low temperatures, although producing no appreciable effect on surfacing time or the length of the removal period as in the case of high pH values, did prolong the time required to kill. However, even at the lowest temperature, 42°F., an estimated complete kill was produced. Both temperature and pH conditions are probably of little consequence or importance when the poison is used at the recommended concentration, 1 p.p.m. This concentration probably would be sufficient to kill all species of freshwater fishes found in North America with the possible exception of the highly resistant goldfish. Based on present prices and the recommended concentration, the cost of sodium cyanide (Cyanegg) is approximately 68 cents an acre-foot.

The period of toxicity was short. This feature of the poison permits restocking of poisoned ponds with a minimum loss of time.

Another important property of sodium cyanide as a fish poison is its ease of application. Little time and equipment are required to apply it. This property is largely dependent on the fact that sodium cyanide is readily soluble in water. The diffusion rate is rapid as indicated by the results obtained when a dip net was used to apply the poison.

The writer considers the most significant findings to be those relating to the removal of live fishes. The results obtained from the poisoning of small farm ponds show that in a relatively short period of time, the desirable fishes of a population can be removed effectively. In addition, the survival of these fishes is excellent. The fact that sodium cyanide permits the removal of live fishes suggests other possible ways it may be used: (1) for collection of live fishes for laboratory or other uses, (2) for the harvest and transfer of fishes in hatcheries, and (3) as an aid in marking fish populations.

Sodium cyanide is highly toxic to humans and care must be exercised in its use. Aside from accidental ingestion, cyanide poisoning can result from inhalation of the gas, hydrogen cyanide. This deadly gas can be produced by inadvertently spilling acid on sodium cyanide. Adequate and relatively inexpensive gas masks may be purchased for protection against the gas. Cyanides are capable of being absorbed through

the skin and therefore lackadaisical handling of them should be guarded against. Sodium cyanide should be limited to use by competent and responsible technicians.

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LITERATURE CITED

Burdick, G. E., and M. Lipschuetz
1948. Toxicity of ferro- and ferricyanide solutions to fish, and determination of the cause of mortality. Trans. Am. Fish. Soc. 78:192-202.

Doudoroff, P.
1956. Some experiments on the toxicity of complex cyanides to fish. Sew. and Ind. Wastes. 28(8): 1020-1040.

Doudoroff, P., and M. Katz
1950. Critical review of literature on the toxicity of industrial wastes and their components to fish. Sew. and Ind. Wastes. 22(11): 1432-1458.

Downing, K. M.
1954. The influence of dissolved oxygen concentration on the toxicity of potassium cyanide to rainbow trout. Jour. Exp. Biol. 31(2):161-164.

Ellis, M. M.
1937. Detection and measurement of stream pollution. Bul. U. S. Bur. Fish. 48(22):365-437.

Lipschuetz, M., and A. L. Cooper
1955. Comparative toxicities of potassium cyanide and potassium cuprocyanide to the western black-nosed dace, (Rhinichthys atratulus meleagris). New York Fish and Game Jour. 2(2):194-204.

Wilne, D.
1950. Equilibria in dilute cyanide solutions. Sew. and Ind. Wastes. 22(7):904-911.

Renn, C. E.
1955. Biological properties and behavior of cyanogenic wastes. Sew. and Ind. Wastes. 27(3):297-308.

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